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(54) IMPROVEMENTS IN SHORT OR VERTICAL TAKE-OFF AIRCRAFT

(71) We, ROLLS-ROYCE (1971) LIMITED, a British Company of 14—15 Conduit Street, London, W1, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to short or vertical take-off aircraft, and is particularly directed to a combination of gas turbine engine and airframe having novel means of controlling the attitude of the aircraft both during take-off and flight.

For a vertical take-off aircraft it is desirable that the ratio of the vertical thrust available from the engine to the total weight of the aircraft be at least 1.2 and preferably higher. Any excess of vertical thrust over this ratio can be traded for stores, range and munitions. During take-off it is necessary be traded for stores, range and munitions. During take-off it is necessary to provide means for controlling and stabilising the aircraft at very low or zero forward speeds when the aerodynamic control surfaces are inoperative. It is now herein proposed to provide a combination of gas turbine engine and airframe capable of giving relatively improved power to weight ratio and attitude control for vertical take-off aircraft.

Vertical take-off aircraft utilising power plants comprising by-pass gas turbine engines in which the bypass flow is exhausted through a first pair of swivellable nozzles and the core engine flow is exhaust through a second pair of swivellable nozzles are well known, for example from the "Harrier" aircraft. Additional thrust for both take-off and level flight is most easily, efficiently and conveniently provided by burning additional fuel in the bypass flow to augment the dry thrust of the engine. Unfortunately the use of such augmented thrust produces a fundamental problem in relation to the balance of the aircraft. In order to balance the aircraft against large pitching moments during vertical take-off the first and second pairs of swivellable nozzles are arranged to discharge one pair to the fore and one pair aft of the centre of gravity of the aircraft and therefore if the thrust from the first pair of swivellable nozzles is augmented relative to the second pair there is a very large pitching moment produced on the aircraft. The magnitude of this problem may be appreciated by considering an aircraft which is required to take-off vertically with a full load of fuel and munitions and for which augmented thrust is essential and which is also required to land vertically having used up its fuel and munitions. The empty aircraft may be half the weight of the full aircraft and this difference in weight will substantially equal the difference between the augmented and non-augmented thrust of the engine. All the additional thrust is provided by one pair of swivellable nozzles situated several feet in front of the centre of gravity of the aircraft thus producing the large pitching moment. For vertical take-off there is, by definition, no forward speed of the aircraft and therefore the conventional aerodynamic control surfaces are ineffective to assist in balancing the large pitching moment.

Provision for controlling the pitch of vertical take-off aircraft has been made in the past by utilizing very high pressure bleeds from the compressor of the core engine as shown for example in U.K. Patent No. 1,036,134. It is not however satisfactory to increase the size of such bleeds in order to balance the large pitching moment produced by the use of augmented thrust for this would degrade the performance of the core engine, thus reducing the bypass flow and adversely affecting the amount of additional thrust available from the first pair of swivellable nozzles.

According to the present invention there is provided an aircraft capable of making vertical or short take-offs and comprising a gas turbine engine and an airframe, the gas

turbine engine having a fan for delivering compressed air to a core engine for driving the fan and to a pair of swivellable nozzles for discharge therefrom, the swivellable nozzles being positioned relative to the aircraft so that for vertical take-off the resultant thrust from the swivellable nozzles acts at or slightly in front of the centre of gravity of the aircraft, there being further provided means for selectively burning fuel in the compressed air delivered to the swivellable nozzles thereby to augment the thrust available from the swivellable nozzles, the fan and core engine being arranged so that, in operation, substantially all the work produced by the core engine is absorbed by the fan and wherein a relatively low pressure discharge from the gas turbine engine is fed, via a duct, to nozzle means at the rear of the aircraft, the nozzle means being capable of discharging said low pressure discharge for pitch and yaw control of the aircraft.

In one embodiment of the invention the relatively low pressure discharge from the engine comprises the exhaust from the core engine. In a further embodiment of the invention the relatively low pressure discharge from the engine comprises a part of the said fan delivery.

The swivellable nozzles may be provided with means for varying the discharge area thereof.

It is desirable that the gas turbine engine should be installed in the airframe such that with the jet efflux from the swivellable nozzles discharging vertically downwards the centre of lift is situated slightly forward of the centre of gravity of the aircraft.

An embodiment of the invention will now be described, by way of example only, with reference to the accompanying drawings in which

Fig. 1 is a plan view of an aircraft;

Fig. 2 is a section of the aircraft of Fig. 1 taken on the line II—II, and illustrating the installed engine;

Fig. 3 is a sectional view of a gas turbine engine suitable for use in an aircraft;

Fig. 4 is an illustration of the attitude control nozzle of the aircraft of Figs. 1 and 2;

Fig. 5 is a similar section to that of Fig. 2 but showing an alternative form of engine installed in the aircraft;

Fig. 6 is a sectional view of the alternative engine of Fig. 5;

Fig. 7 is a similar section to that of Fig. 2 but showing an alternative form of attitude control nozzle;

Fig. 8 is an illustration of the alternative attitude control nozzle of Fig. 7;

Fig. 9 is a section on the line IX—IX of Fig. 8.

Referring to Figs. 1 and 2 a vertical take-off aircraft 10 comprises a gas turbine engine 11 installed in an airframe 12. Two forward facing intakes 13 and 14 situated on either side of the fuselage 15 of the aircraft supply air to the gas turbine engine which is shown in detail in Fig. 3. A large fan 16 delivers most of its output past a flow splitter 17 which divides the flow of compresesd air into two streams each directed through a respective nozzle 18 (only one shown) which is swivellable about an axis 19 to vary the direction of discharge therefrom. Upstream of each nozzle is a plurality of gutters 20 on which a flame may be established for selectively burning fuel in the plenum space 21 to augment the thrust available through the nozzles 18. Each nozzle 18 is to be provided with means 22 for varying the flow area thereof to accommodate the variation between augmented and non-augmented flow. Such nozzle means are well known per se and may for example be of the kind described in U.K. Patent No. 1,278,801.

A further relatively small part of the fan delivery is passed along the duct 23 to a high pressure compressor 24 of the core engine 25 which provides the work for driving the fan 16. The output from the high pressure compressor is passed to a combustion chamber 26 wherein it is mixed with fuel and the mixture burned. The products of combustion then drive a high pressure turbine 27 connected by a shaft 28 to the high pressure compressor 24 and a low pressure turbine 29 connected to the fan 16 by a shaft 30. The arrangement is such that substantially all the work produced by the core engine over and above that necessary to drive the high pressure compressor is absorbed in driving the fan 16 thus the pressure of the jet efflux in the duct 31 of the low pressure turbine is relatively low and in this embodiment is about 4 lbs/sq. in. gauge. By substantially is meant that about 90 per cent of the work available from the core engine is absorbed in driving the fan 16.

The jet efflux is exhausted from the duct 31 through nozzle means 32 situated at the tail of the aircraft. The duct 31 can be seen to be of considerable length but it need not be unduly heavy because the pressure in it is relatively low.

The nozzle means 32, which can be understood more clearly from Fig. 4, is capable of discharging the jet efflux for pitch and yaw control of the aircraft and comprises four pairs 33 of pivotally supported channel section members. Each pair has a first channel section member 34 hinged about its upstream edge 35 and a second downstream channel section member 36 hinged about its downstream edge 37. Each pair 33 of members co-operate to exhaust the jet efflux from the nozzle means 32 in any direction between forwardly, radially and rearwardly of

the axis 38 of the engine. Thus for example to direct the jet efflux rearwardly the member 36 is moved about its downstream edge 37, by jack means not shown but well known per se, to the position 39 in which is follows the contours of the outer surface 40 of the duct 31 and the member 35 is similarly moved about its upstream edge 35 to the position 41 thus presenting a rearwardly directed discharge opening 42.

It will be seen that for rearward discharge the jet efflux flows over the closed end 44 of the duct 31 which terminates in the well known 'boat tail angle' for the avoidance of base drag. Radial discharge 45 of the jet efflux is achieved by moving the channel section members 34, 36 to the positions 46, 47 respectively in which they present a radially facing discharge opening 48. Forward discharge of the exhaust gases for braking purposes is not illustrated but it will be readily appreciated that this is achieved by reversing the positions 39, 41 of the two members 34, 36.

For yaw control of the attitude of the aircraft the nozzle pairs 33 lying in the lateral plane are used, thus if it is desired for the aircraft to jaw to the right and right hand pair of members 33 are moved to the radial discharge position. Variation in the degree of yaw required is selected by greater or lesser movement of one or other of the members 34, 36 to discharge the jet efflux at an angle intermediate between radially and forwardly or rearwardly.

Pitch control of the aircraft is similarly achieved by using the two pairs of nozzles 33 that lie in a vertical plane through the aircraft.

It will be appreciated that the pilot 49 may control the pitch and yaw of the aircraft by directly linking the actuation of the nozzle pairs 33 to his joystick.

The two swivellable nozzles 18 are situated such that their line of thrust for vertical take-off lies immediately under or just forward of the centre of gravity 52 of the aircraft. This yields a significant advantage in that the difference in thrust between augmented and non-augmented flow from the nozzles 18 does not result in a large pitching moment on the aircraft and does not therefore present significant attitude control problems. It is not strictly necessary to provide the nozzle pair 33 situated on top of the duct 31 as it will be appreciated that the thrust balance between the two swivellable nozzles 18 and the nozzle pair 33 situated underneath the fuselage may be adjusted by, for example, varying the direction of discharge of the swivellable nozzles. This swivelling action may be combined with the transition to forward flight when the aerodynamic control surfaces 50 become effective in assisting the attitude control of the aircraft.

For assisting in rapid turning manoeuvres in flight the nozzle means 32 may of course be used either in place of or in addition to the aerodynamic control surfaces of the aircraft.

A yet further advantage derives from the use of a single pair of swivellable nozzles 18 for providing the main propulsive thrust of the aircraft, and their positioning close to the centre of gravity of the aircraft, inasmuch as the swivellable nozzles are well behind the intakes 13 and 14 to the engine thus reducing the likelihood of hot gas re-ingestion degrading the performance of the engine. Hot gas re-ingestion could present an especial problem to an aircraft utilising augmented flow from swivellable nozzles but the problem is minimised by the present invention. Hot gas re-ingestion may be further minimised in aircraft according to the invention by arranging the axis 19 of each swivellable nozzle 18 so that for vertical take-off the jets from the two swivellable nozzles coalesce on or above the ground 51 thus preventing the occurrence of an upward fountain of hot air which could flow along the underside of the fuselage and into the intakes 13 and 14. Providing the angle at which the jets from the two swivellable nozzles are inclined is kept relatively small there will not be a significant loss in the vertical thrust component of the engine. The rear wheels 53 of the retractable tricycle undercarriage 54 are mounted on the wings 55 to prevent the tyres being effected by the hot gas exhaust from the engine.

An advantage of discharging the turbine exhaust in the manner herein described is that only two swivellable nozzles 18 are required for providing the main propulsive thrust for the aircraft and thus its drag coefficient is relatively reduced over other constructions utilising more swivellable nozzles.

Under certain circumstances the use of a duct for conveying hot exhaust gases from the core engine to the rear of the aircraft is undesirable and there is shown now with reference to Figs. 5 and 6 an alternative engine arrangement for obviating the hot exhaust duct within the airframe.

In Figures 5 and 6 like numerals refer to like parts as described previously.

An aircraft 10 capable of making short or vertical take-offs comprises a gas turbine engine installed in an airframe 12. The gas turbine engine is shown in more detail in Fig. 6 from which it can be seen that the air received from the intakes is compressed by a large fan 16 and the fan delivery is divided into three parts by a flow splitter 56. A first part of the fan delivery at a relatively low pressure of 14 lbs/sq. in. gauge provides a cooling air flow for the engine car-

case and is subsequently conveyed via a duct 57 to a nozzle means 32 at the rear of the aircraft, the nozzle means 32 being capable, as explained before, of discharging the part for pitch and yaw control of the aircraft.

A second part of the fan delivery is passed from the flow splitter 56 to a high pressure compressor 24 of the core engine 25. Substantially all the work produced by the core engine is absorbed in driving the fan 16 and therefore there is only a relatively low pressure exhaust discharge from the core engine and this discharge is passed to atmosphere through a pair of swivellable nozzles 58 themselves well known per se.

The third part of the fan delivery, which is the largest part, is discharged to atmosphere by means of a second pair of swiveltable nozzles 18 at the front of the engine. Both pairs of swivellable nozzles 58, 18 are capable of discharging the flow through them in any direction from forwardly through downwardly to rearwardly relative to the axis of the engine. Means, not shown, but well known in themselves, for example in British Patent Specification No. 987,564 are provided for burning fuel in the third part of the fan delivery to augment the thrust available from the front pair of swivellable nozzles 18. Such means is known as plenum chamber burning (P.C.B.). In order to efficiently cope with variations in delivery from the front nozzles due to the use or non-use of plenum chamber burning each nozzle is provided with means 22 for varying the flow area thereof.

The delivery from the rear swivellable nozzles 58 forms only a relatively small component of the thrust available from the gas turbine engine even without the use of plenum chamber burning at the front swivellable nozzles 18. Thus it is possible to position the front swivellable nozzles only slightly forward of the centre of gravity 52 of the aircraft and produce an aircraft which is balanced during vertical take-off with both pairs of swivellable nozzles pointing downwardly. If plenum chamber burning is then selected, because the front nozzles have only a small moment arm about the centre of gravity of the aircraft, the augmented thrust from the front swivelalble nozzles does not dramatically imbalance the aircraft. The nozzle means 32 at the rear of the aircraft is adapted to selectively produce a relatively small downward discharge which, by virtue of its long moment arm from the centre of gravity of the aircraft, is sufficient to balance any turning moments produce by the augmented thrust from the front swivellable nozzles. It will be appreciated that plenum chamber burning may also be deployed when the aircraft is in forward flight and because the line of action of the front swivellable nozzles is below the centre of gravity of the aircraft the nozzle means at the rear of the aircraft may again be called upon to balance the aircraft. Of course in forward flight the air control surfaces of the aircraft are also available to assist in attitude control thereof.

Whilst the first part of the fan delivery is shown passing through a duct 59 for cooling the engine carcass it will be appreciated that the third part could merely be collected in a manifold (not shown) and passed directly into the duct 57.

It will be further appreciated that the swivellable nozzles 58 could be replaced by other types of nozzles for example a single lobster tail nozzle well known per se.

The nozzle of Fig. 4 may be replaced with other types of nozzle e.g. in Fig. 7 the four nozzle pairs 33 are replaced by an alternative nozzle means 60 which from Figs. 8 and 9 can be seen to comprise four butterflies 61, 62, 63, 64 which co-operate with a pair of buckets 65, 66 hinged together at 67, 68 which can be moved to the position 69 to obstruct the end of the jet pipe 70 and allow the jet efflux to exhaust through whichever of the four butterflies is selected to be operative via the plenum chamber 71. Thus pitch and yaw control of the attitude of the aircraft is achieved by selecting an appropriate combination of openings of the butterflies.

As the attitude control nozzle means 32 or 60 are exhausting only a relatively small amount of the propulsive energy of the gases from the gas turbine engine their relative efficiency need not be exceptionally high and therefore relatively simple, inexpensive and lightweight constructions may be adopted without being unduly detrimental to the power to weight ratio of the aircraft.

As the majority of the work available from the core engine is absorbed in driving the fan the temperature of the core engine exhaust is relatively low thus it will be appreciated that parts downstream of the core engine may readily be fabricated from sheet metal with attendant advantages.

The term swivellable nozzles has been used through the specification to refer to the pipe bend nozzles as illustrated in the drawings however, it will be appreciated that the term may also be applied to rotatable cascades known per se and as shown in U.K. Patent Specification No. 913,312 without any loss of generality.

WHAT WE CLAIM IS:—

1. An aircraft capable of making vertical or short take-offs and comprising a gas turbine engine and an airframe, the gas turbine engine having a fan for delivering compressed air to a core engine for driving the fan and to a pair of swivellable nozzles for discharge therefrom, the swivellable

nozzles being positioned relative to the aircraft so that for vertical take-off the resultant thrust from the swivellable nozzles acts at or slightly in front of the centre of gravity of the aircraft, there being further provided means for selectively burning fuel in the compressed air delivered to the swivellable nozzles thereby to augment the thrust available from the swivellable nozzles, the fan and corme engine being arranged so that, in operation, substantially all the work produced by the core engine is absorbed by the fan and wherein a relatively low pressure discharge from the gas turbine engine is fed. via a duct, to nozzle means at the rear of the aircraft, the nozzle means being capable of discharging said low pressure discharge for pitch and yaw control of the aircraft.

2. An aircraft as claimed in claim 1 and wherein the relatively low pressure discharge from the gas turbine engine comprises the core engine exhaust.

3. An aircraft as claimed in claim 1 and wherein the relatively low pressure discharge from the gas turbine engine comprises a part of the fan delivery.

4. An aircraft as claimed in claim 3 and wherein the core engine exhaust is discharged from the aircraft through further nozzle means capable of varying the direction of discharge thereof.

5. An aircraft substantially as herein described with reference to and as shown in Figures 1 and 2.

6. An aircraft substantially as herein described with reference to and as shown in Figure 5.

For the Applicants,
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Chartered Patent Agent.

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1473088 COMPLETE SPECIFICATION

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Sheet 1

FIG. 1

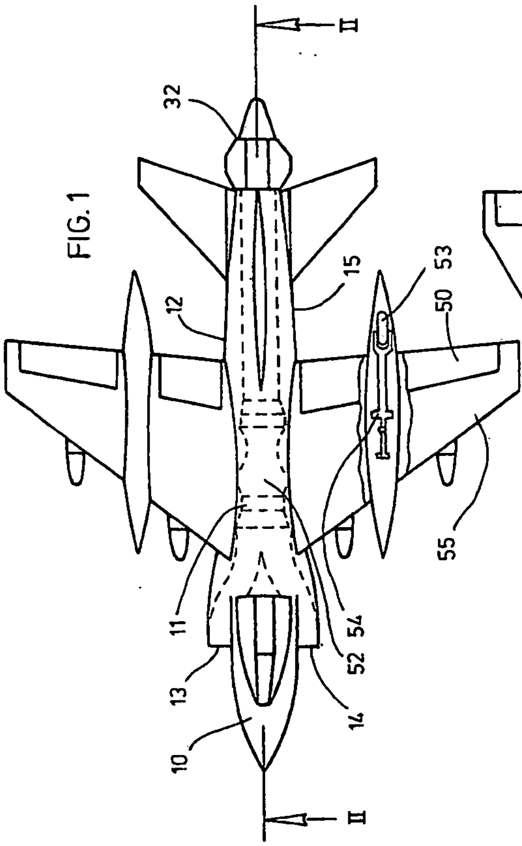
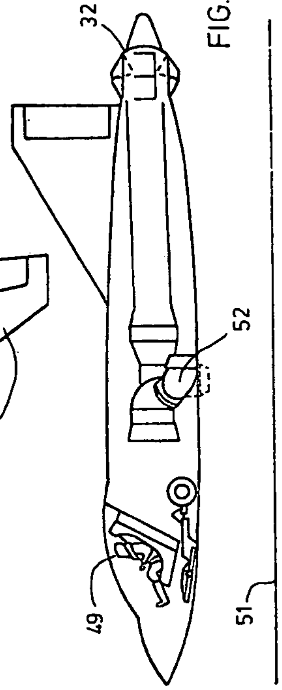


FIG. 2.



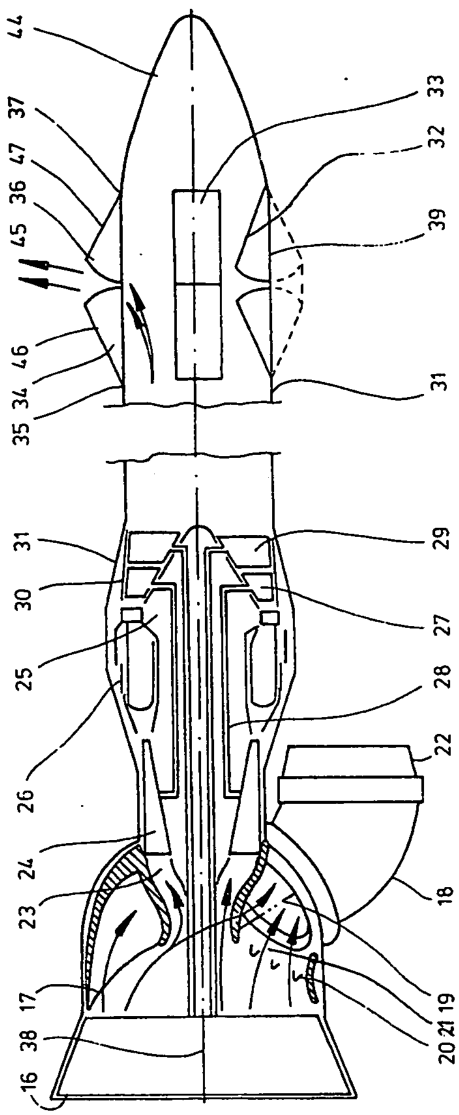

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FIG. 3

1473088 COMPLETE SPECIFICATION

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Sheet 3

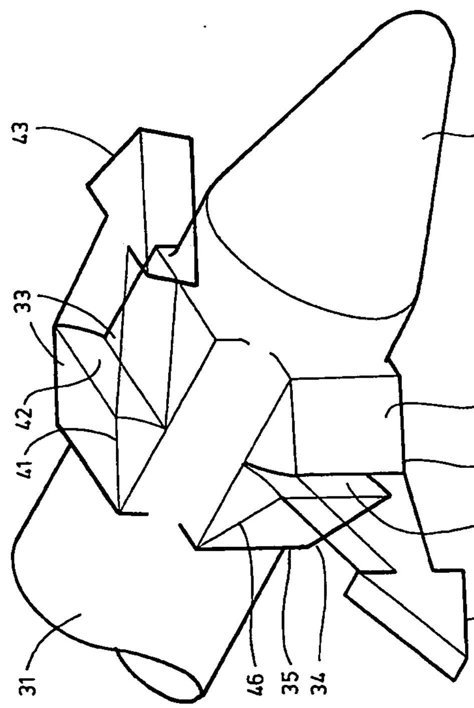

FIG. 4

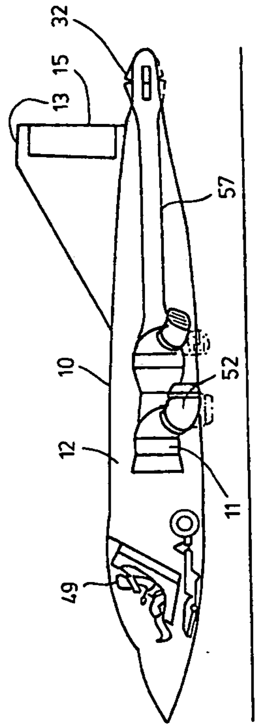

FIG. 5

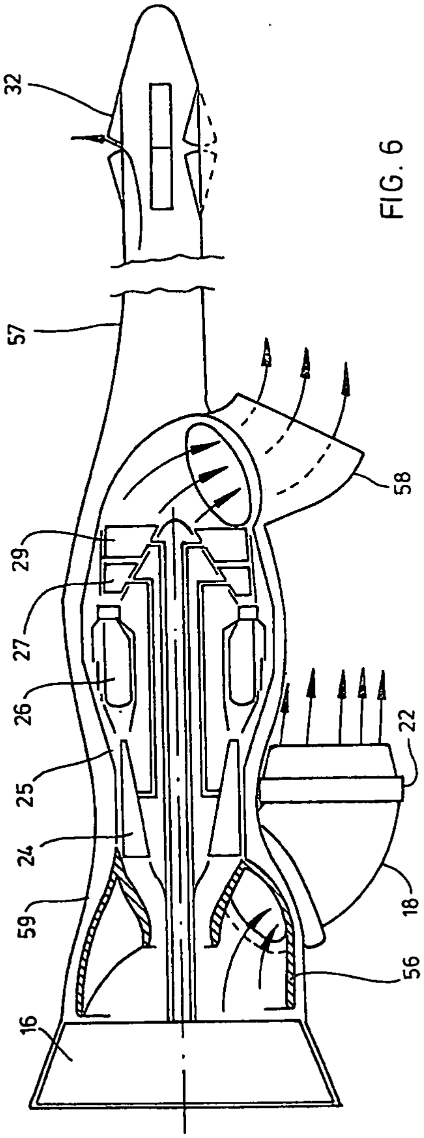

FIG. 6

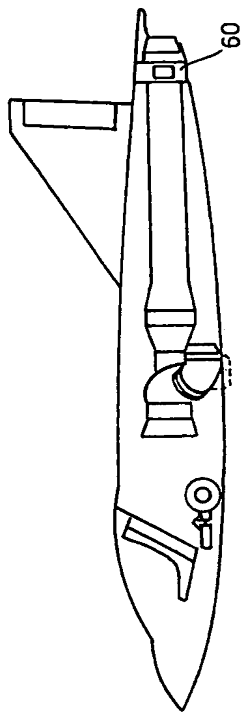

FIG. 7

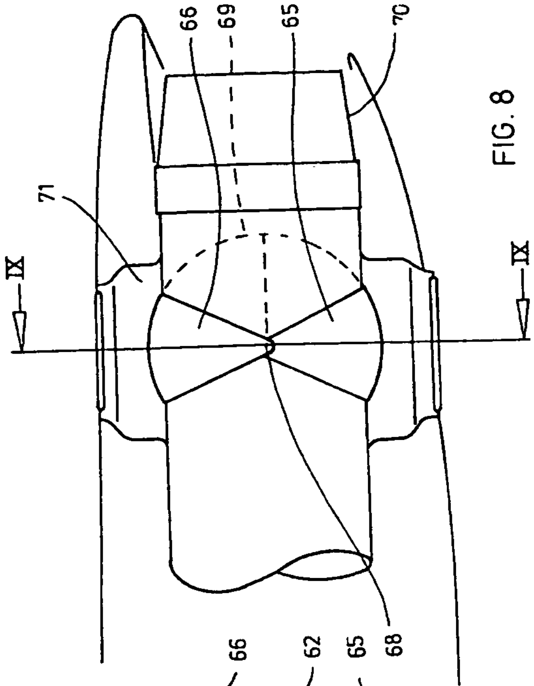

FIG. 8

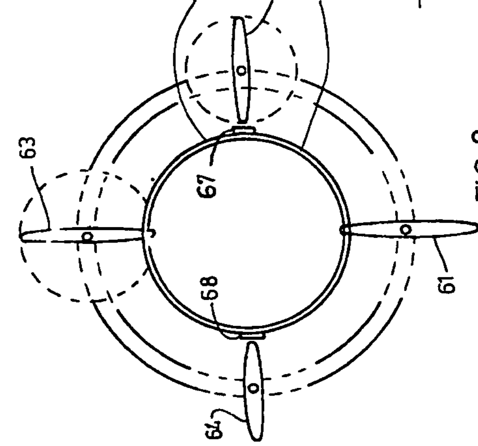

FIG. 9